National Bureau of Standards

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Further Development of the NBS Magnetic Fluid Clutch

The NBS Magnetic Fluid Clutch is characterized by ease of control, high efficiency, smooth operation, long life, and simplicity of construction. It is thus particularly suited to applications in servo mechanisms, automatic machinery, automotive service, and other fields where these characteristics are important.

Since this clutch was originally developed by the National Bureau of Standards in 1948, its unique features have made it the subject of extensive investigation in both Government and industrial laboratories. As a result, valuable information has been obtained on a number of problems—such as heat dissipation, settling of the magnetic powder, and hermetic sealing—that are important in industrial applications of the clutch. Meanwhile, the basic principle of the Magnetic Fluid Clutch—itself an innovation in science—is being utilized to make possible other significant developments in science and industry.

Invented by Jacob Rabinow of the Bureau staff, the Magnetic Fluid Clutch is based on Mr. Rabinow's discovery that the frictional forces between solid surfaces and certain types of fluid media can be controlled by the application of magnetic fields. In its simplest form the device consists of two parallel magnetic plates separated by a powder composed of finely divided magnetic particles. When a magnetic field is established between the two plates, the magnetic particles bind the plates against movement parallel to their surfaces.

The magnetic particles may be finely divided iron which for most applications is mixed with a liquid, such as oil, to prevent packing and to afford smoother operation. When a portion of this mixture is acted on by a magnetic field, the iron particles are mutually attracted, bind together in the field, and the mixture seemingly solidifies. As slipping occurs only between extremely fine iron particles and between the iron particles and the smooth face surfaces of the clutch, and as all surfaces are lubricated, practically no wear occurs in the clutch.

Early in the development of the Magnetic Fluid Clutch, it was recognized that lubricants other than oil could be used with magnetic powders to give the desired results and that the clutch could even be operated entirely without lubricant. Louis Schuman, of NBS, suggested in 1948 that graphite or other dry lubricants such as talc or molybdenum might be used, and the Bureau made tests that showed that these materials were satisfactory. Heavy grease lubricants have also been suggested for this purpose. To date, the Bureau has tested approximately 300 lubricating mixtures of all kinds for use in the clutch.

Heat Dissipation

Dissipation of the heat produced by slippage is one of the most serious problems in all types of clutches and brakes. While air or liquid cooling can, of course, be used in the Magnetic Fluid Clutch, special devices such as heat exchangers have been constructed and have proved satisfactory. Improved methods of sealing

permit operation at high temperatures, which enable the clutch to dissipate heat at a faster rate.

At the suggestion of the National Bureau of Standards, an investigation of the thermal conductivity of magnetic fluids was carried out by Commander D. B. Bell and Lt. Commander G. S. Bennett at the United States Naval Postgraduate School, Annapolis, Md. The material tested was carbonyl iron powder "E" (experimental lot, with small particles removed) in USP light mineral oil. Two thousand eighty grams of iron powder were suspended in 300 grams of oil, giving approximately a 7-to-1 mixture. Four drops of polyethylene glycol oleate were added as a wetting agent. The equipment used did not permit very high flux densities, the highest being about 3,400 lines per square inch. In the temperature range from 56° to 70° F, which the investigation covered, it was found that approximately 5 Btu were conducted per square foot of cross section per degree Fahrenheit per inch of path length. Research conducted by the Raymond Engineering Laboratory has shown that this heat conductivity value is not affected materially by the higher flux densities.

If a liquid lubricant is used with the magnetic powder, the mixture itself can serve as a cooling medium when the clutch is demagnetized. The lubricant can be pumped throughout the clutch so that the heat is carried away from the working gap, where it is generated, and is dissipated through the body and the shafts of the clutch. When the mixture is strongly magnetized, however, the iron particles are not mobile and it is not possible to circulate the oil through the particles freely if the quantity of iron is appreciable. This difficulty has been overcome by pumping the excess lubricant through special passages without carry-

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Charles Sawyer, *Secretary*

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E. U. Condon, *Director*

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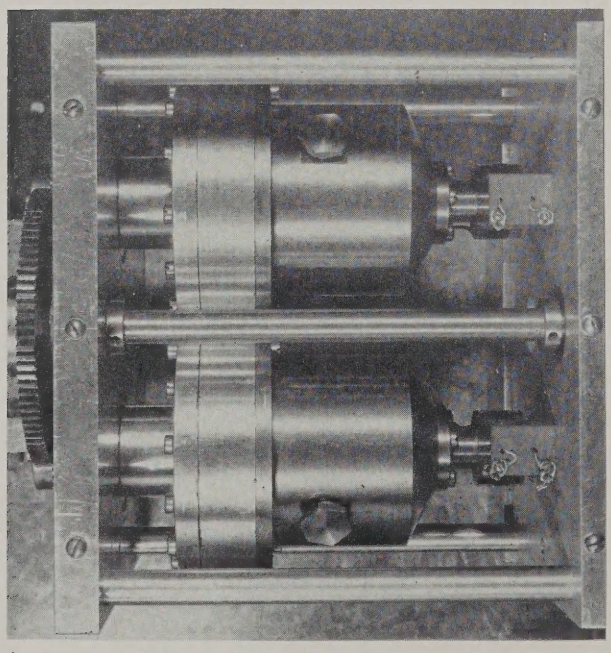
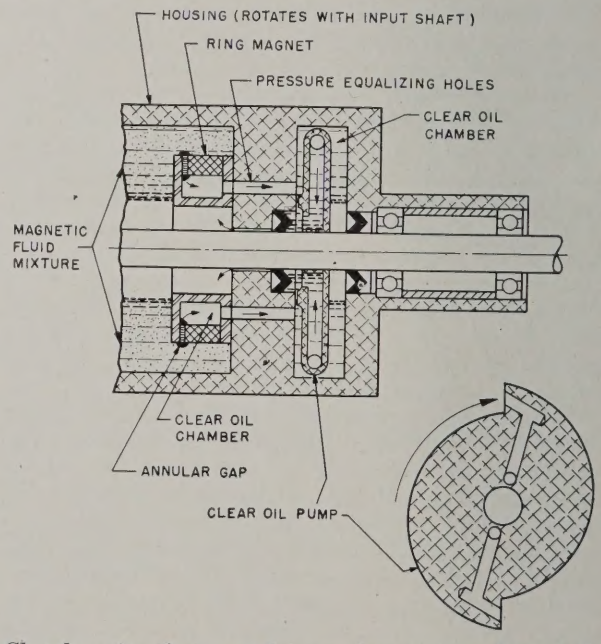
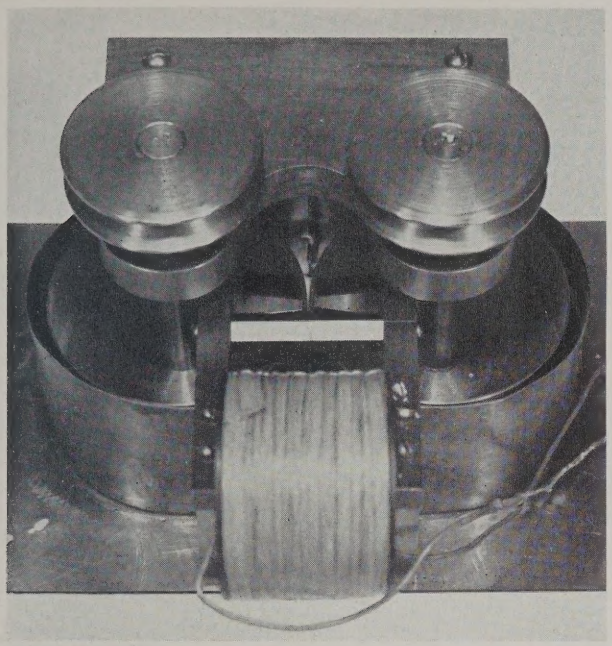




A servo mechanism (left) embodying two Magnetic Fluid Clutch units that use the new hermetic seal recently developed by the Bureau. In this seal (right) clear oil from a reservoir is continuously pumped along the shaft (see arrows) into the interior of the clutch. The clear oil is then returned to the reservoir (arrows) through a magnetic separator which prevents passage of the iron powder. A second seal operates entirely in clear oil.



A magnetic transmission that utilizes the principle of the Magnetic Fluid Clutch. The friction between solid surfaces is replaced by the friction between solid surfaces and a magnetic powder.

ing the iron powder. Centrifugal force and magnetic attraction have been used to separate the iron from the coolant.

The use of solid lubricants such as graphite has enabled some workers to operate the clutch at higher temperatures than could be maintained with oils without pressure seals. Here dissipation of heat is facilitated by the higher operating temperature of the clutch, which permits more rapid transfer of heat to the cooler surroundings.

Sealing

Several schemes have been used to keep the iron powder and the lubricant in the clutch cavity. One obvious method of doing this is to arrange the clutch in such a manner that no shaft seal is required. If the clutch is mounted vertically, for example, its lower part can be so enclosed that gravity will maintain the particles where they belong. However, this vertical type of mounting imposes limitations that are not always acceptable. Also, the stirring of the material is more difficult than in a clutch where the shaft is horizontal. In any case, an open clutch is desirable only when the temperatures are low and where the "breathing" of air is limited.

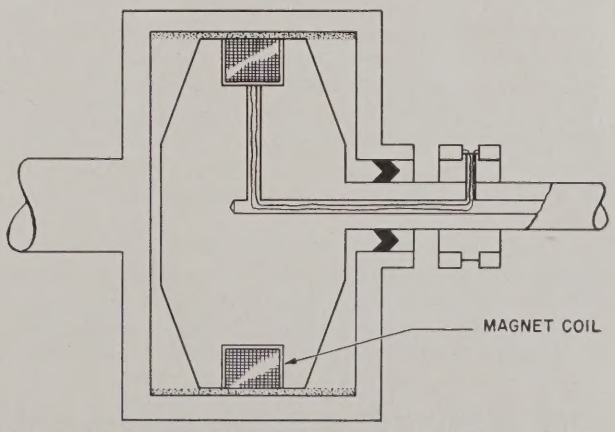
Labyrinth seals have been employed in magnetic clutches, with varying degrees of success. If the speed of the clutch is always high, the labyrinth can be made quite effective by utilizing the centrifugal forces on the powder. Where the speeds are variable and the positions of the clutch are undetermined, as in some military airborne applications, the use of labyrinths has not proved satisfactory. Labyrinths, moreover, do not prevent breathing. Thus, as the clutch warms up, air is driven out, and as the clutch cools, cold air enters again, carrying with it fresh oxygen and moisture, which corrode the internal parts of the mechanism and the iron powder.

For these reasons, hermetic sealing appears to be most desirable. A satisfactory hermetic seal that was developed by the National Bureau of Standards under Navy sponsorship consists of a reservoir of clear oil, mounted adjacent to the clutch proper, so designed that the clear oil is continuously pumped along the shaft into the interior of the clutch. The clear oil is then returned to the reservoir through a magnetic separator, which prevents iron particles from flowing with the oil. The magnetic separator consists of a ring magnet of Alnico having a very short air gap. The iron powder does not pass the air gap, while the oil does so quite freely. An impeller-type pump then recirculates the oil back through the shaft seal. The whole system is provided with a second seal that operates entirely in clear oil. Such seals are commercially available and are quite satisfactory. Clutches sealed in this way have operated at speeds from 120 to 1,440 rpm, and at slips varying from zero to 200 percent, for 30 days with no visible evidence of iron particle leakage.

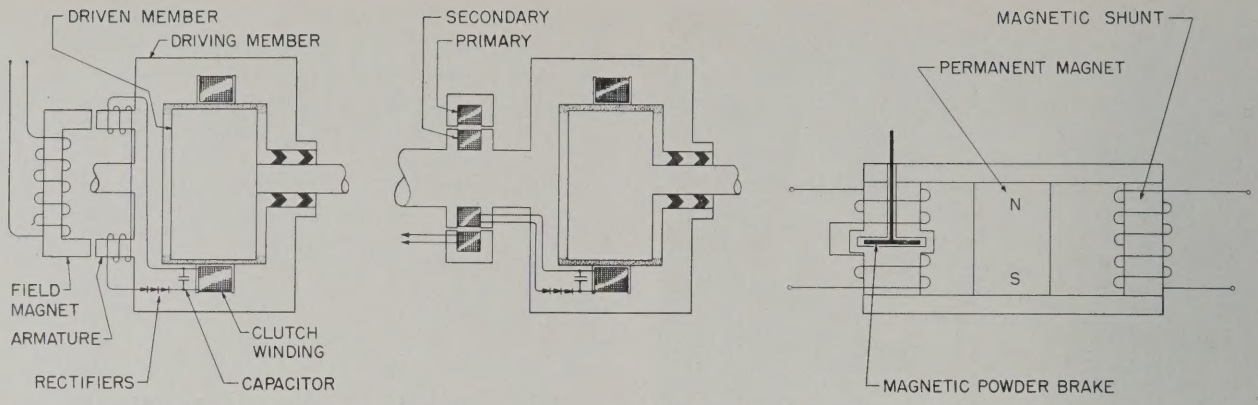
When thick grease lubricants are used in magnetic fluid clutches, the sealing problem is somewhat simpler, as the iron-grease mixture tends to stay in the working gap. Air intake, however, causes trouble, and hermetic seals are still required to make the clutch independent of ambient conditions. This is also true of clutches employing dry lubricants.

Settling of the Iron Powder

When the magnetic fluid clutch was first developed, it was anticipated that the settling of the iron powder during standstill periods might cause difficulties.



In the coaxial-cylinder type of Magnetic Fluid Clutch, the effect of centrifugal force on the magnetic particles is minimized by using only enough iron powder to fill, or not quite fill, the working gap between the cylinders. The centrifugal forces are then overcome by the magnetic forces at moderately high speeds.



Left: Self-excited Magnetic Fluid Clutch. A generator built into the clutch produces alternating current that is rectified and sent through the clutch coils. The magnetic field is varied either by changing the electromagnetic field of the generator or by moving the field magnet toward or away from the armature. Center: Transformer-excited Magnetic Fluid Clutch. The stationary primary structure induces current into the secondary, which is mounted on the clutch. Right: Two-way shunt system used with a magnetic-powder brake based on the principle of the Magnetic Fluid Clutch. Application of current shunts the flux away from the brake, releasing the brake without demagnetizing the permanent magnet. Such a system is of advantage where it is undesirable for the brake to be released by power failure.

However, as the clutch stirs itself very effectively, this has not proved to be a major source of trouble. In some applications, where the clutch serves as an overload device or where permanent magnets are used and the clutch is never demagnetized, settling presents no problem at all.

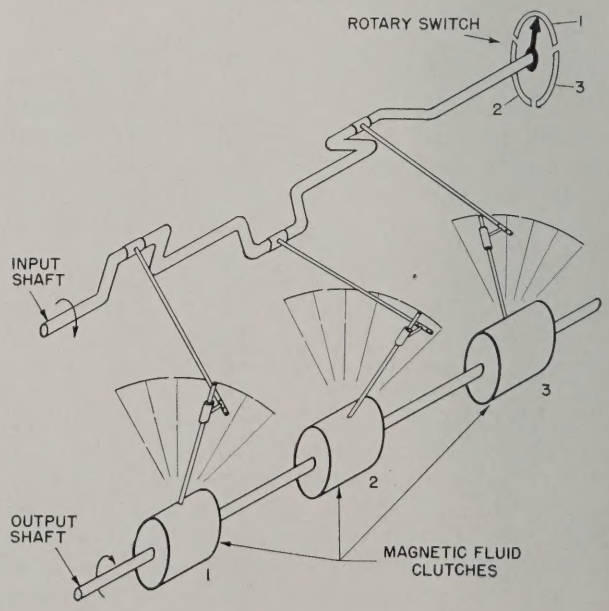
If settling is undesirable for special reasons, it can be minimized in several ways. For example, some residual magnetism may be left in the iron during periods of disuse to keep the particles in their normal position. This means, of course, that more elaborate electrical controls are required where it is necessary to have the clutch release completely. Thixotropic greases, which resist flow but are easily stirred, can be employed to minimize settling, or the gaps can be so designed that the iron powder is kept in essentially the right place by mechanical locks on each side of the gap. The use of wetting agents, suggested by H. D. Saunderson of NBS, has been found to make the magnetic fluid easily miscible and to give it thixotropic properties. It has been reported that where graphite is used as the lubricant, centrifugal force produces a hard-packed iron-graphite mass that stays in place when the clutch is not operating.

Centrifuging Problem

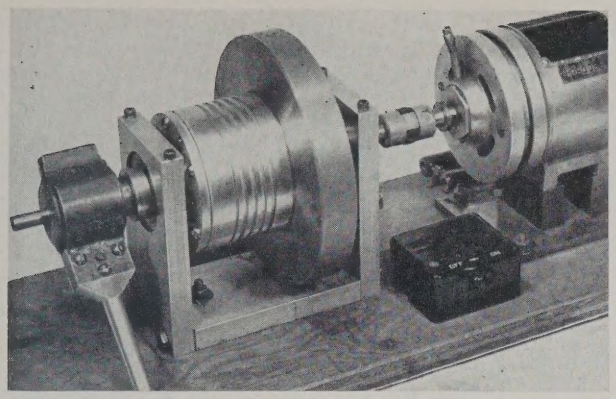
In some of the early magnetic fluid clutches, difficulties were caused by the pressures produced on the iron particles by centrifugal force. In fact, some clutches of this type would not release at high speed. In disk-type clutches the effect was particularly noticeable, as the centrifugal pressures on the iron particles in these clutches may be equal to or greater than those developed by magnetic attraction.

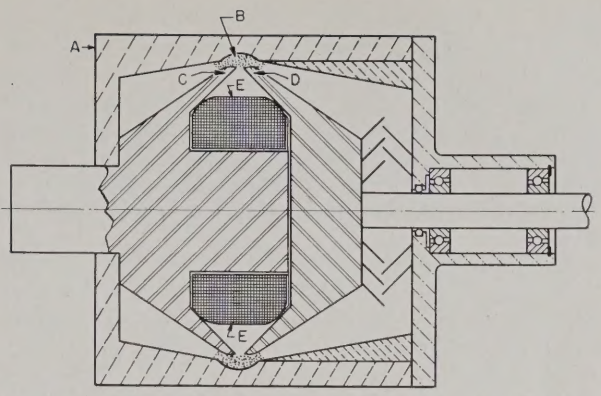
In most of the clutches now being built, the driving and driven parts are two coaxial cylinders. These clutches avoid difficulties due to centrifugal force by using only enough iron powder to fill or not quite fill the working gap beween the cylinders. Additional space can be filled with oil, or not, as desired. Then at moderately high speeds the centrifugal forces on the particles are overcome by the magnetic forces. This keeps the particles in the gap for operation of the clutch.

When still higher speeds are required, however, the simple cylindrical clutch is not entirely saisfactory, as the magnetic forces are not then great enough to bal-



An oscillating variable-speed transmission in which rotation is first converted to an oscillatory motion and then transformed, by means of clutches, back to rotary motion. Use of the Magnetic Fluid Clutch in this mechanism has been suggested for smoother and more efficient operation. By means of the rotary switch, the proper Magnetic Fluid Clutch can be energized.





High-speed Magnetic Fluid Clutch. The outside case (A) is made of nonmagnetic material, and the working gap is concentrated in the small space (B) external to the pole pieces (C and D) of the driving and driven members. The clutch is excited by the coil (E).

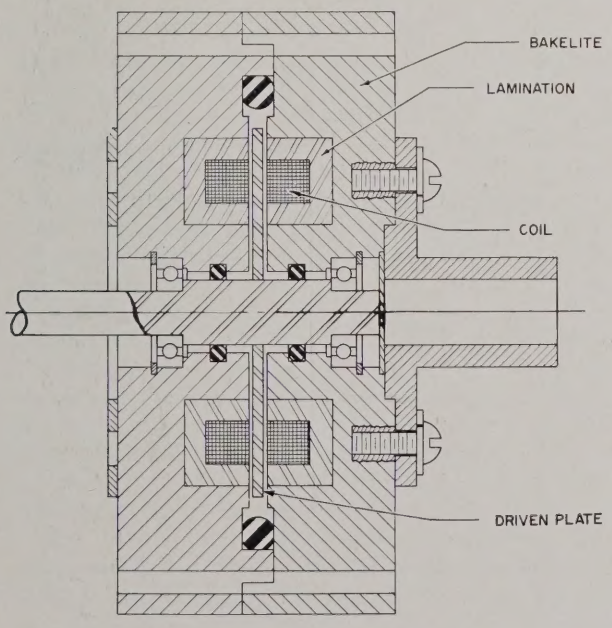
ance the centrifugal forces. The Bureau therefore developed a clutch of special design to operate at speeds of 10,000 rpm or more. In this clutch, the outside case is made of nonmagnetic material, and the working gap is concentrated in a small annular volume just inside the outer case and enclosing the two circular pole pieces. In this way the magnetic forces are made to act against the centrifugal forces and to overcome them for high speeds. Another advantage of this type of clutch is that when the magnetic field is removed, the particles separate from either or both of the magnetic surfaces, and the clutch releases completely. If no excess lubricant is used, there is no drag.

Electrical Problems

The electromagnetic field for operation of the clutch can be energized by means of an external source of electrical power connected to the clutch by slip rings, or a stationary magnet may be used to transmit the flux to the working members through air gaps. Another possibility is to build a generator into the clutch itself. The alternating current thus produced can be rectified by suitable means and fed through the clutch coils. One advantage of this technique is that permanent-magnet excitation can be used for the generator. Also, since the clutch requires only a very small amount of electrical energy, the generator can be simple and of inexpensive design. The magnetic field can be varied either by changing the electromagnetic field of the generator or by moving the permanent magnet toward or away from the poles.

Use of a transformer provides still another method of exciting the clutch. A stationary primary structure induces alternating current into a secondary that is mounted on the clutch and separated from the primary by two small air gaps. This alternating current is either used directly in the clutch windings or converted to direct current by suitable rectifiers.

For many applications it is desirable that the clutch be kept locked most of the time and be released only when current is applied. This is particularly necessary in hoists, for example, in order that power failure may not cause the release of a brake or a clutch. One of the best ways of doing this employs a permanent magnet, so arranged that the application of current shunts the flux away from the clutch into a bypass, thus releasing the clutch without demagnetizing the permanent magnet. Various mechanical methods for controlling the flux from permanent magnets either by moving the magnet itself or by moving appropriate shunts have been suggested. Some of these employ the principle of the magnetic chuck used in grinders and lathes for holding work pieces. In some applications where demagnetization is permissible, the clutch is controlled by magnetizing and demagnetizing "permanent" magnets.



A fast-acting Magnetic Fluid Clutch in which a very short response time is obtained by laminating the magnetic structure.

Speed of Response

It has been found that the response time of the clutch—that is, the time required to energize and de-

energize it—depends almost entirely on the response rate of the magnetic circuit rather than on the action of the iron particles. The speed of response of the magnetic circuit, in turn, is a function of the inductance of the winding and of the voltage of the source that supplies the current. As in all magnetic devices, laminating the iron structure aids in reducing eddy currents, which tend to slow up the rise and decay of magnetic fields.

Invention of the Magnetic Fluid Clutch has suggested a number of possible applications in which the iron particles could be used for purposes other than merely locking two members together. Soon after the development of the Magnetic Fluid Clutch, W. S. Hinman of the Bureau staff suggested that magnetic-particle friction could be used for the transmission of power between cylinders, cones, and other structures that are not necessarily coaxial. In such variations of the old cone-and-disk type of variable-speed friction devices, the friction between solid surfaces is replaced by friction between solid members and a magnetic powder.

It has also been suggested that magnetic fluid clutches could be substituted for the one-way clutches used in oscillating variable-speed transmissions. In these mechanisms, a rotary motion is first converted to an oscillatory motion, which is then transformed, by means of one-way clutches, back to a rotary motion at a lower speed. Speed is varied by changing the stroke of the oscillatory motion. By use of magnetic fluid clutches with properly excited magnetic fields, a considerably smoother and perhaps more efficient transmission of this type could be achieved than has previously been possible.

Selected Bibliography

Magnetic fluid clutch, NBS Tech. News Bull. **32,** 54 (1948).

Jacob Rabinow, The magnetic fluid clutch, Trans. AIEE **67,** 1308 (1948).

E. S. Bettis and E. R. Mann, A servo employing the magnetic fluid clutch, Rev. Sci. Instr. **20,** 97 (1949).

R. S. Elberty, Clutches—character and design of magnetic fluid types, Machine Design **21,** 98 (1949).

New uses for magnetic fluids, NBS Tech. News Bull. **33,** 74 (1949).

G. R. Nelson, Magnetic fluid clutch in servo applications, Electronics **22,** 100 (1949).

W. G. Martin 3d, Magnetic particle clutches, Elect. Manufacturing **46,** 109 (1950).

U. S. Patent No. 2,500,953 (Mar. 21, 1950).

U. S. Patent No. 2,519,449 (Aug. 22, 1950).

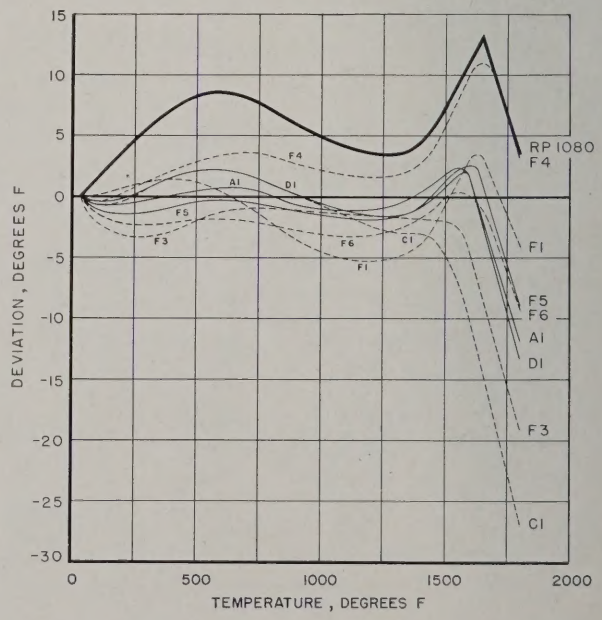
U. S. Patent No. 2,525,571 (Oct. 10, 1950).

Standardization of Iron-Constantan Thermocouple Tables

The iron-constant thermocouple is widely used in industry for measurement of temperatures up to 1,500° F. Yet it is the only type of thermocouple for which uniformity of commercial practice has not been established in this country. Recently, at the request of the Scientific Apparatus Makers of America, the National Bureau of Standards has undertaken to derive a temperature-emf reference table for iron-constantan thermocouples that would be suitable for adoption as a standard.

The temperature-emf tables for thermocouples that the Bureau has issued from time to time have been used extensively in science and industry, not only to convert thermocouple voltages into the equivalent measured temperatures, but also in the preparation of purchase specifications for thermocouple wire and in defining the relation between impressed emf and scale reading for pyrometers that indicate temperature directly. In practice, the calibration of an individual thermocouple is ordinarily given in terms of deviations from such a reference table. As it is usually not convenient to change the scale of a direct-reading pyrometer to compensate for variations in the thermocouples that may be used with it, thermocouples are commonly purchased under specifications that ensure that they will correspond closely to the graduation of the particular model of pyrometer used.

Some time ago, an investigation of iron-constantan thermocouples by the Bureau disclosed that the thermocouples of this type that were then commercially available did not follow closely any of the several temperature-emf relations for iron-constantan in use by py-



Deviations observed at the National Bureau of Standards between readings of sample iron-constantan thermocouples and the 1913 (L&N) temperature-emf table are shown by the dashed and fine continuous lines. The heavy line indicates differences between the RP 1080 and the 1913 tables.

rometer manufacturers. (Reference tables for iron-constantan and copper-constantan thermocouples, William F. Roeser and Andrew I. Dahl, J. Research NBS **20,** 337 (1938) RP1080). The Bureau therefore derived a new table, usually known as the RP1080 table, which represented the average behavior of the iron-constantan thermocouples on the market. However, rather than alter the scales of their pyrometers to conform to the actual properties of the thermocouples then being sold, most of the various manufacturers made efforts to develop and make available thermocouples that would correspond to the temperature-emf tables they were using. As a result, a number of widely diverse reference tables for iron-constantan thermocouples are still in use.

In an effort to achieve greater uniformity, the Recorder-Controller Section of the Scientific Apparatus Makers of America, representing several of the pyrometer manufacturers, in 1948 adopted the temperature-emf relation known as the 1913 (L&N) table (Identical with the tables given in International Critical Tables **1,** 59 (1926) and in Tech. Pap. BS **14,** 306 (1920–21) T170, Table IV, Col. L.) as a tentative standard for iron-constantan thermocouples over the range from 32° to 1,400° F. This relation was chosen because it is in wider use than any other. However, experience has shown that it is apparently not possible to produce a thermocouple that will correspond precisely to the 1913 table over the entire range from 32° to 1,400° F. Moreover, any thermocouple that closely matches this table in the range below 1,400° F will deviate greatly from it in the range above 1,400° F. The SAMA therefore requested the National Bureau of Standards to derive a reference table that would be free from these defects. It was felt that such a table should be as close to the 1913 table as possible, yet should represent the properties of an actual commercially available thermocouple.

Eight different lots of matched iron and constantan wires were submitted to the Bureau by four members of SAMA. The thermal emf's of the various wires versus platinum were measured in the Bureau's pyrometry laboratory from 32° to 1,800° F. From these data, the corresponding thermal emf's for the iron-constantan thermocouples were computed. In addition, chemical and spectrographic analyses of the iron samples and hardness determinations were made. It was found that the spread in the thermal emf's of the iron-constantan thermocouples below 1,400° F was not large compared to usual commercial tolerances, even though the iron samples differed among themselves by as much as 0.8 millivolt at 1,400° F (equivalent to about 20 degrees in the indication of an iron-constantan thermocouple) and the constantan samples differed similarly. Present preference is to base the new SAMA table upon the temperature-emf relation of thermocouple A–1, as this thermocouple deviates least from the 1913 table in the range of normal use.

The question may now be raised whether the field of use of this proposed new table can be broadened through industry-wide acceptance. Support by this Bureau for any new table (taking the form of official publication and possibly resulting in inclusion in a Federal Specification) might conceivably cause hardship to suppliers and users of iron-constantan themocouples who have based their operations on the RP1080 table. Thus, it is felt that the views of all interested parties should be obtained as a prerequisite to the adoption of this table. The questions that naturally occur if the proposed table can be adopted are the following: Is industry-wide standardization on a single reference table for iron-constantan desirable? Is the 1913 table, or a close approximation to it, acceptable for this purpose? What degree of hardship will be occasioned by abandonment of the RP1080 table? The reaction of producers and users of pyrometers is a matter of interest to the Bureau, and replies to the above questions as well as related comments can be addressed to the National Bureau of Standards, Temperature Measurements Section, Washington 25, D. C.

High-Frequency Measurements Conference

The second High-Frequency Measurements Conference sponsored jointly by the American Institute of Electrical Engineers, the Institute of Radio Engineers, and the National Bureau of Standards will be held in Washington, D. C., on January 10 to 12, 1951. The introductory address will be delivered by Dr. Edward U. Condon, Director of the Bureau.

Sessions covering Measurements of Frequency and Time; Impedance; Power and Attenuation; and Transmission and Reception are planned. The present program is tentative in order to permit inclusion of some last-minute papers on outstanding developments.

Three demonstration lectures to be staged Thursday evening, January 11, 1951, will highlight the conference. These will be held in the Department of the Interior Auditorium and will constitute the Annual Joint Meeting of the local AIEE and IRE Sections.

The National Bureau of Standards will display a Microwave Spectroscope in operation with the aid of a projection oscilloscope. The Bureau will also demonstrate a Recording Microwave Refractometer adapted for atmospheric measurements. An outstanding speaker of the evening will be Dr. Winston E. Kock of Bell Telephone Laboratories, who will present a new and striking demonstration of the parallel behavior of microwaves and centimeter wavelength sound waves.

The Conference is under the general direction of Prof. Ernst Weber, of the Microwave Research Institute of the Polytechnic Institute of Brooklyn, as Chairman of the Joint AIEE-IRE-NBS Committee on High-Frequency Measurements. Dr. Harold Lyons of the NBS is Chairman of the Local Arrangements Committee, and Dr. Frank Gaffney of the Polytechnic Research and Development Company is Chairman of the Technical Program Committee.

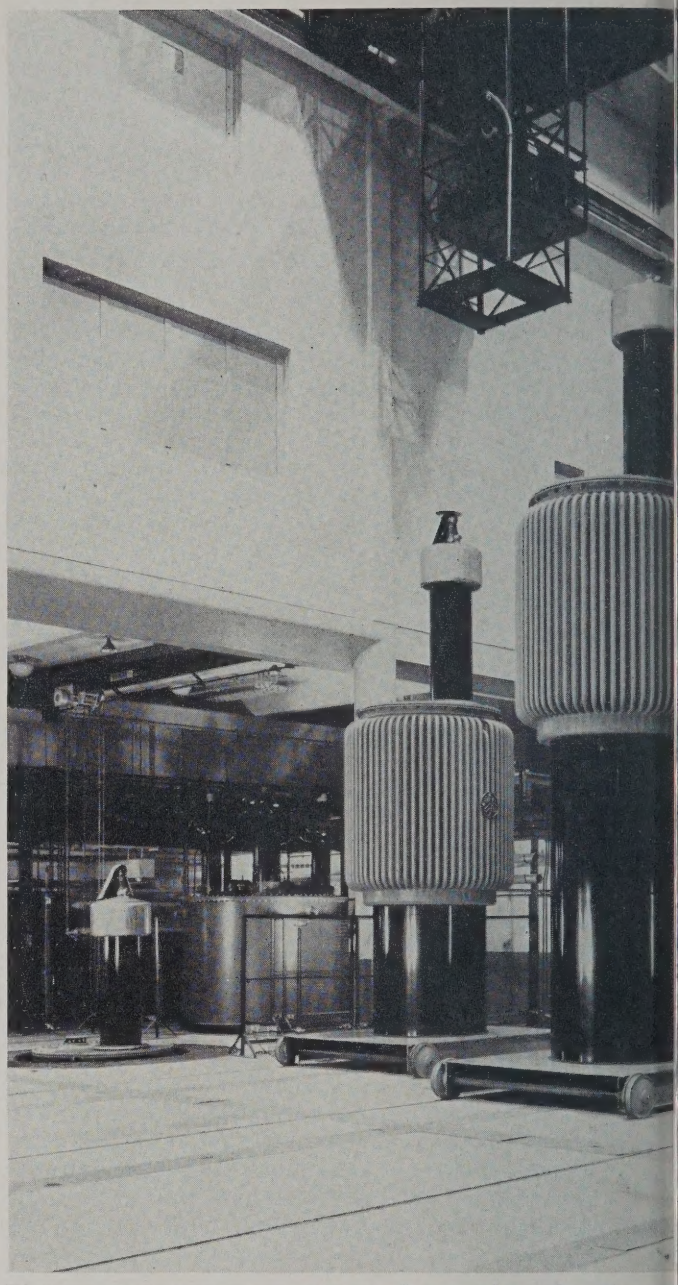
Standards for Ele

Precise electrical measurements are of fundamental importance to modern science and industry. This is true not only in the communication and power fields but in many other areas where the flexibility and convenience of electrical methods have made them almost indispensable for the measurement of nonelectrical quantities. Thus, while in textbooks energy is defined simply in terms of force and length or of mass and velocity, in actual practice the heat energy of fuels and the energy output of prime movers are universally measured to high precision by electrical methods. Likewise, the basic electrical units enter into the determination of nearly all the fundamental atomic constants, as well as into daily measurements of heat, light, color, strain, acceleration, displacement, and chemical properties.

Effective application of electrical equipment and measurement methods requires uniformity to a high degree of precision in the basic electrical units. Some two billion dollars' worth of electrical machinery and apparatus is manufactured annually in this country. Were each manufacturing company to use an even slightly different value for the volt or the ohm, the apparatus made by its subcontractors would fail to function properly as a part of the final product. The result would be an impossibly confused situation, causing large financial losses to the Nation. In the communications industry, the multiplex transmission of intelligence over a relatively small number of circuits is dependent on the precise adjustment of capacitance, inductance, and other circuit components in such a way as to prevent the signals from straying into the wrong channels. This, again, requires precise uniformity in the measurement of the basic electrical units.

As the custodian of the national standards of physical measurement, the National Bureau of Standards has the responsibility of insuring that the units of measurement used in science and industry are constant through the years and uniform throughout the Nation. The Bureau has developed very precise standards of resistance and voltage whose values are established by absolute measurements that fix the relation between the electrical units and the fundamental mechanical units of length, mass, and time. From these basic absolute electrical standards, the Bureau has derived other standards for all electrical quantities in use today.

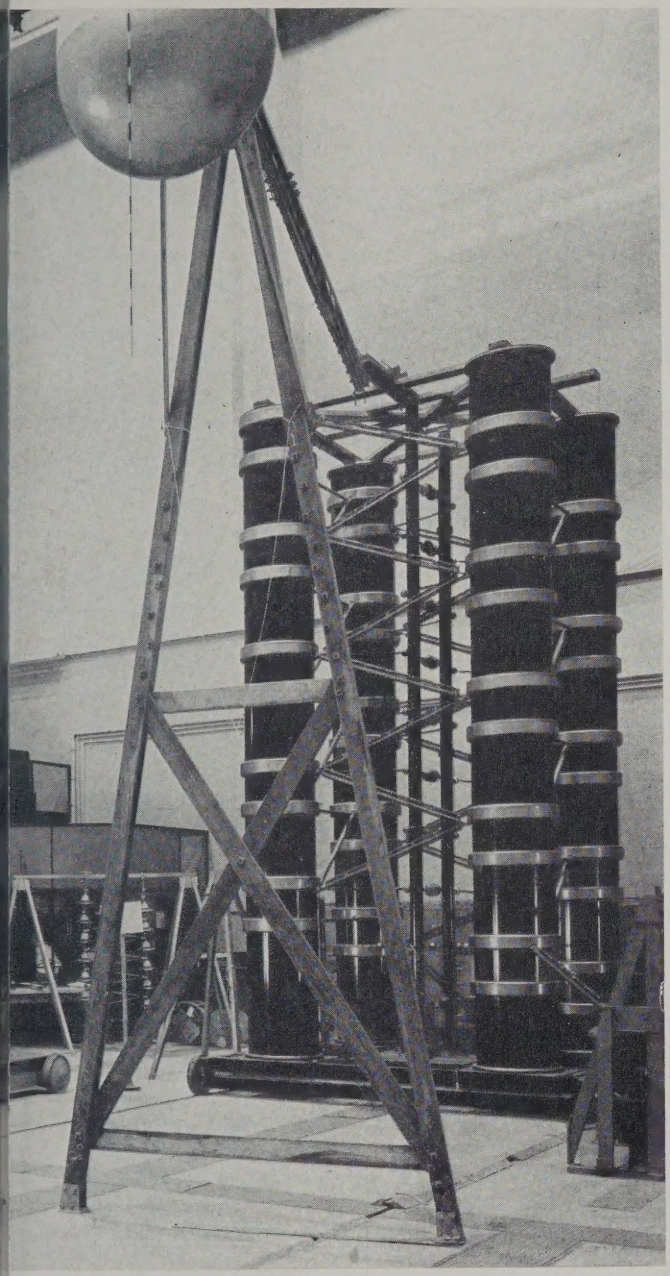
Because of their technical difficulty, precise absolute measurements are carried out only in the national standardizing laboratories of a few of the larger countries. Sufficient accuracy in science and industry is obtained through accurate comparison of the secondary or working standards of other laboratories with primary standards thus calibrated. In this country such comparisons constitute the Bureau's calibration service. Each year a stream of about 2,000 high-grade electrical instruments, standard cells, and other measuring apparatus flows through the Bureau's electrical laboratories. The services performed range from the comparatively simple measurement of the emf of a standard cell to the determination of the ratio and phase angle of a multirange current transformer at several frequencies, currents, and loads, which may require



The apparatus shown is used to study very short-duration su equipment. At the right is the 2,000,000-volt surge generator, The large transformer in the left background (with smooth ta with its primary windings in parallel and is then used with t of the instrument transformers submitted for test. The two for the measuring circuit and for other 60-cycle tests.

1,000 separate measurements. Among the devices submitted are potentiometers, bridges, resistance boxes, volt boxes, capacitors, inductors, multimegohm resistors, instruments and meters of all kinds, precision shunts for large currents, instrument transformers,

cal Measurement



f high voltage and intense current used to test high-voltage ich improved voltage-measuring circuits are being developed. s voltage ratings of 125,000 and 250,000 volts. It is calibrated vindings in series as a standard for checking the exact ratio ransformers (center), rated at 350,000 volts, serve as a supply

standard magnetic test bars, magnetic test coils, and standard cells of both the saturated and unsaturated types. They come from manufacturers of electrical equipment, from public utility companies wishing to make sure that their charges are correct, from public service commissions which regulate the utility companies, and from communication laboratories, university laboratories, private commercial testing laboratories, and the many scientific laboratories of the Federal Government.

The demands of modern science and technology have made this work more and more exacting, not only as regards accuracy, but also in the range of values and variety of units in which measurements are made. Thus the Bureau now measures precisely currents, voltages, and resistances having values up to tens of thousands of amperes, hundred of thousands of volts, and millions of billions of ohms. This is done with direct current, with alternating current of various frequencies up into the thousands of megacycles per second, and with surges of current lasting only a few millionths of a second.

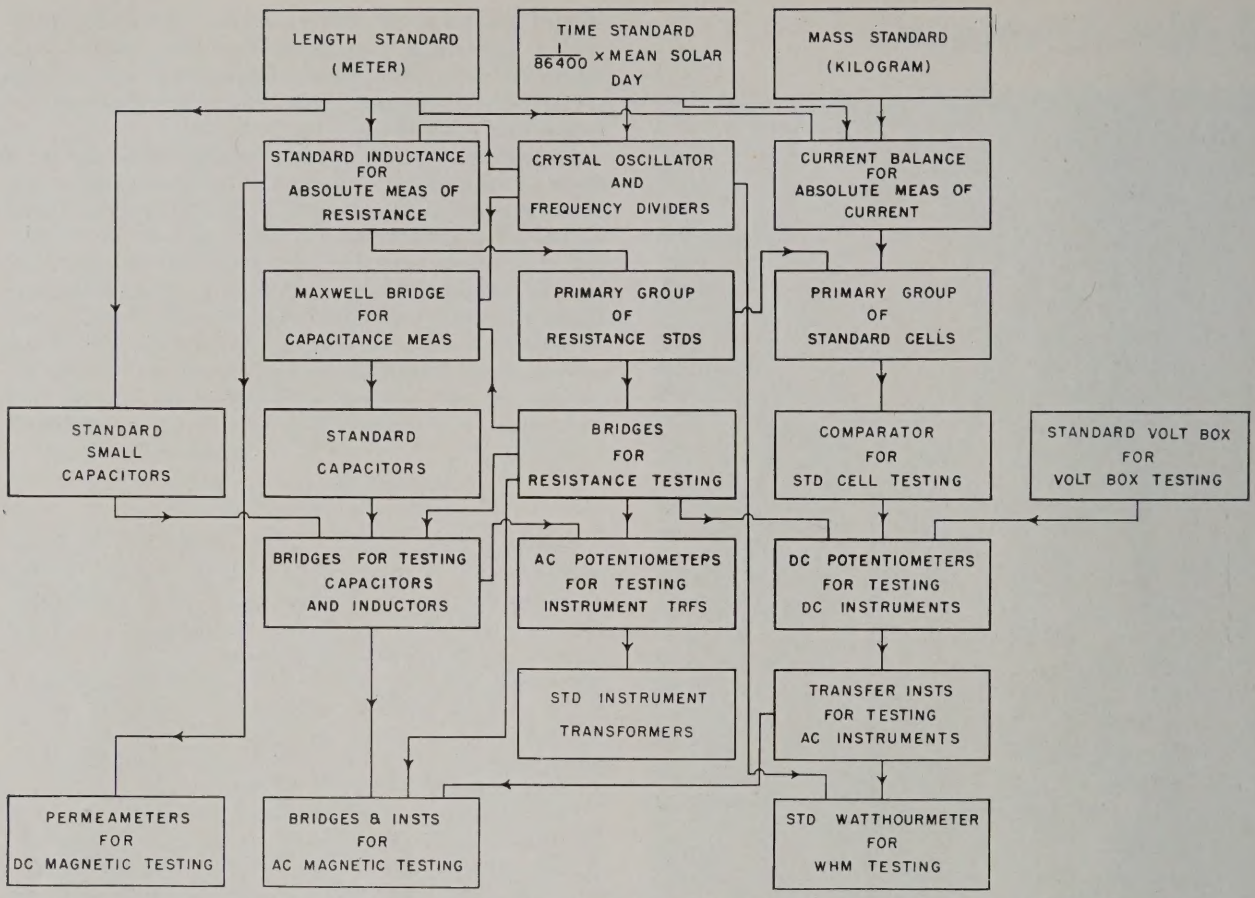
Establishment of Units

The basis of the Bureau's standardization of electrical measurements is the establishment of values for the ohm and the ampere that bear the desired simple theoretical relation to the meter, the kilogram, and the second. However, as an electric current is by its nature evanescent, the volt, derived from the absolute ampere at the time the latter is measured, is embodied in the calibration of a group of standard cells, which together with the standard resistors embodying the ohm, are kept as permanent primary standards.

The determination of the ohm consists of two steps. The first is the construction of an inductor (either self or mutual) that is so designed that its essential dimensions can be measured mechanically with high accuracy and that is of such a shape that the inductance can be calculated from these measured dimensions. Both self and mutual inductors have been prepared at the Bureau by winding wire in lapped helical grooves on forms of glass, quartz, or porcelain. The second part of the process consists of an electrical experiment in which a bridge or equivalent circuit is used to compare the reactance of the inductor at a known frequency with the resistance to be measured. When the resistance in absolute ohms of the resistors used in the bridge circuit has been determined in this way, the absolute resistance of other standard resistors can be found by comparison.

A current is measured in absolute amperes by determining the mechanical force between two parts of the circuit in which it flows. In the center of two large fixed coils, a small coil is hung from the arm of a precision balance. All three coils carry the current to be measured, but the current in the fixed coils can be reversed. The small electromagnetic force developed by the current in the coils tends to pull the movable coil downward for one direction of the current in the fixed coils but tends to lift it when this current is reversed. From the change in the force on the balance when the current is reversed and from the measured dimensions of the coils, the value of the current in absolute amperes can be computed.

A second feature of this experiment makes use of the standard current while it is being "weighed" to


LENGTH STANDARD (METER)
TIME STANDARD 1/86400 × MEAN SOLAR DAY
MASS STANDARD (KILOGRAM)
STANDARD INDUCTANCE FOR ABSOLUTE MEAS OF RESISTANCE
CRYSTAL OSCILLATOR AND FREQUENCY DIVIDERS
CURRENT BALANCE FOR ABSOLUTE MEAS OF CURRENT
MAXWELL BRIDGE FOR CAPACITANCE MEAS
PRIMARY GROUP OF RESISTANCE STDS
PRIMARY GROUP OF STANDARD CELLS
STANDARD SMALL CAPACITORS
STANDARD CAPACITORS
BRIDGES FOR RESISTANCE TESTING
COMPARATOR FOR STD CELL TESTING
STANDARD VOLT BOX FOR VOLT BOX TESTING
BRIDGES FOR TESTING CAPACITORS AND INDUCTORS
AC POTENTIOMETERS FOR TESTING INSTRUMENT TRFS
DC POTENTIOMETERS FOR TESTING DC INSTRUMENTS
STD INSTRUMENT TRANSFORMERS
TRANSFER INSTS FOR TESTING AC INSTRUMENTS
PERMEAMETERS FOR DC MAGNETIC TESTING
BRIDGES & INSTS FOR AC MAGNETIC TESTING
STD WATTHOURMETER FOR WHM TESTING

Block diagram shows steps used in deriving precise values for all the electrical units from the basic mechanical units of length, mass, and time. It also shows how the Bureau applies these standards to the testing of electrical apparatus.

measure directly the emf of a standard cell in absolute volts. This is done by arranging the standard cell so that its electromotive force is exactly balanced by the drop of potential produced in a known resistance by the standard current. The emf of the cell is then computed by Ohm's law.

A group of 25 standard cells and another group of 10 carefully constructed 1-ohm standard resistors serve to preserve the values of the volt and of the ohm from day to day and from month to month. The various members of each group of standards are intercompared at intervals of a few months; and as long as their relative values are constant, it is assumed that the absolute mean value of the group has also remained constant. If an individual standard is found to have drifted relative to the others in its group by a significant amount since the previous intercomparison, it is rejected and replaced by another standard that has a good record of performance. The process of comparing a resistor with the standard mutual inductor is so convenient that it is frequently used as an independent check on the constancy of the group of standard resistors. However, the mechanical measurement of the dimensions of the inductors and of the current balance is so very tedious and time-consuming that this experimental work is carried through only once in a decade as the final check on the constancy of both types of standard.

From the standard ohm and the volt thus maintained at the Bureau, the other electrical and magnetic units are derived by a variety of experimental procedures. The farad is precisely obtained by charging and discharging an air capacitor at a known rate in a Maxwell commutator bridge. The henry is determined by comparison with capacitors and resistors in a Maxwell-Wien bridge. The ampere is reestablished, when desired, by measuring with a potentiometer the drop it produces in a known resistance. The ampere and the volt are combined to give the watt, and the joule and kilowatt hour are derived by maintaining a known number of watts in a circuit for a measured length of time. The gilbert and the oersted are computed from the number of ampere-turns used in magnetizing a magnetic test specimen in a permeameter of known geometry. The gauss and maxwell are obtained from the deflections of a ballistic galvanometer, which, in turn, is calibrated by reversing a measured current in a known mutual inductor.

This specially constructed self-inductor permits determination of the ohm in absolute measure to an accuracy of a few parts in a million. The 1,000 turns of the coil are wound in a lapped helical groove on a Pyrex glass form about 35 centimeters in diameter and 1 meter long. The diameter and average pitch of the coil have been measured to one part in a million. Its inductance is 103 millihenries.

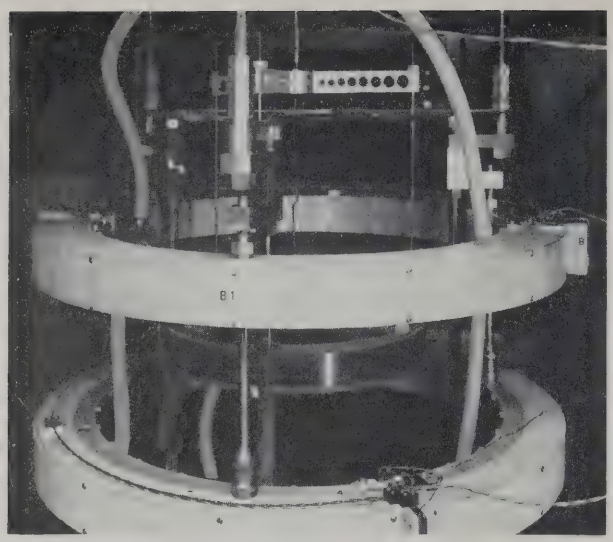
Extension of Ranges

The extension of the scale of measurement of any of the electrical quantities to other ranges is based, in large part, upon the establishment of a ten-to-one ratio in a special, highly accurate bridge. By successive application of the ratio, resistances as low as 0.00001 ohm or as high as ten million ohms can be accurately measured. Still higher resistances up to 10^{18} ohms are measured by more complex methods, such as the determination of the rate of accumulation of charge in a known capacitor. Inductance and capacitance measurements are extended over wide ranges by means of ratio arms of known resistance ratio. However, determination of standard capacitances below 1 micromicrofarad is based upon an independent set of measurements involving the construction of air capacitors of such shapes that their capacitance can be computed precisely from their dimensions.

Direct currents as high as 10,000 amperes are measured with a potentiometer and standard resistors of low value so constructed that their temperature and resistance are not affected by the very considerable heat developed when large currents are used in them. Direct voltages up to 1,500 volts are measured by means of potential dividers, or volt boxes. The ratios of the dividers are derived by connecting in series groups of resistors whose relative individual values have been found by substitution methods. Specially constructed resistors, shielded to avoid corona discharge, are used in X-ray testing to measure direct-current potentials as high as 1,400,000 volts. In the upper part of this range additional shields separately maintained at appropriate intermediate potentials are required.

The great bulk of the electrical energy generated and utilized throughout the country is distributed as alternating current. The step from the direct-current standard cell to alternating-current measurements of voltage, current, and power is therefore of fundamental importance. For 60-cycle work, the transfer is carried out by means of two specially constructed astatic electrodynamic instruments, a wattmeter, and a voltmeter. In these instruments the moving coils are supported by taut strip suspensions, and the position of the moving coils is indicated by a spot of light on a scale at a distance equivalent to a pointer 13 feet long. The wattmeter has been carefully compared both with a quadrant electrometer and with the loss in a capacitor that had been tested in a Schering bridge; such measurements have established the accuracy of the two electrodynamic instruments at frequencies up to 3,000 cycles. Directly or indirectly, the accuracy of practically all the alternating-current instruments used in the transmission of electrical energy depends on these two standard instruments. For tests of ammeters and voltmeters at 400 cycles and above, transfer circuits employing thermocouples are also used.

In commercial practice the range of alternating current is extended upward from 5 amperes by means of calibrated current transformers. Thus, an important part of the Bureau's calibrating service consists of the calibration of standard current transformers which, in turn, are used by manufacturers and electric utility companies to calibrate their working transformers. Special four-terminal standard resistors, constructed so as to have negligible skin effect and a known computable inductance (hence a known phase angle), are used to measure the ratio and phase angle of transformers up to 2,500 amperes with a specialized form of alternating-current potentiometer. Beyond this limit, up to 12,000 amperes, the unknown transformer is compared with a multirange standard transformer, which is calibrated on its lower ranges by the use of standard resistors and is then used as a standard on its higher ranges. Careful study of this standard transformer has given assurance that its various ranges bear simple integral ratios to one another.



The coils of this current balance "weigh" current for the absolute determination of the ampere. The smaller coil is suspended, coaxial with the two larger coils, from the pan of a sensitive balance. When a current flows through all three coils in series, the mechanical force between the small and the large coils is measured with the balance. From the value of this force and the dimensions of the coils, the ampere is computed.

Similarly, the extension of the alternating-current voltage scale above 150 volts is, in practice, based upon the use of voltage transformers. A special shielded resistor, capable of operating at 30,000 volts, is used to measure the effective ratio and phase angle of voltage transformers up to this limit and also to check the performance of standard multirange transformers when they are connected for 25,000 volts. These multirange transformers can then be connected for 50,000 or for 100,000 volts and used as standards at these latter ratings. A still larger standard transformer is calibrated with its coils in parallel at 100,000 volts and used with its coils in series as a standard up to 250,000 volts.

For all this testing and calibration work, other than that performed for the Federal and State Governments, the law requires the Bureau to charge an appropriate fee. These fees are high enough to avoid subsidized competition with private testing laboratories but are low enough to make it possible for all industrial laboratories to attain high accuracy where desirable in their work. In any event, the cost to both Government and industry of the Bureau's electrical standardization services is slight in comparison with the savings to the Nation that result from the program. For example, the electrical power industry has now grown to the point where the annual bill for electrical energy is approximately four billion dollars. If there were a consistent error of 1 percent in the standards used at the Bureau to calibrate the electric meters with which the industry calibrates its customer meters, either the power companies or the consumers would lose 40 million dollars each year. Yet the cost of maintaining the Bureau's service in this field is much less than 1 percent of the discrepancy.

The Bureau is currently making efforts to meet the demand for ever-increasing volume and complexity in electrical standardization work. Techniques are being developed for the more accurate measurement of man-made lightning—very short-duration surges of high current—that are coming to be used by electrical manufacturers to test high-voltage equipment. Methods are also being worked out for the more rapid and economical checking of watt-hour meters; the testing of the very high resistances now used in measuring ion currents and other radiation effects; and the testing at 400 and 1,000 cycles per second of instruments and instrument transformers for use on aircraft and in induction furnaces for heat-treating metals.

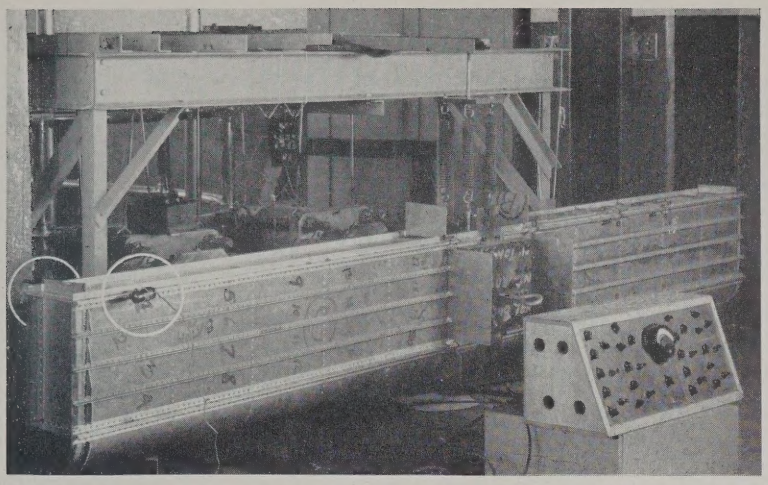
Note: *National Bureau of Standards Circular 475, Establishment and maintenance of the electrical units, by F. B. Silsbee, is available from the U. S. Government Printing Office at 25 cents a copy.*
For fees and other information on the testing and calibration program, see National Bureau of Standards Circular 483, Testing at the National Bureau of Standards, available from the U. S. Government Printing Office at 25 cents a copy.

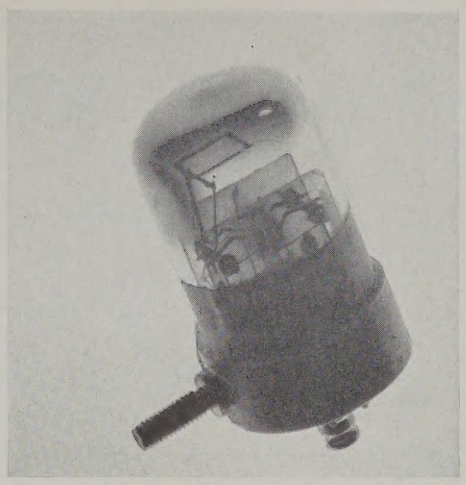
The Improved Ramberg Vacuum-Tube Accelerometer

Recent research in the Engineering Mechanics Section of the National Bureau of Standards has resulted in an improvement of the Ramberg vacuum-tube accelerometer, which NBS developed in 1946 for the Navy's Bureau of Aeronautics with the cooperation of Sylvania Electric Products, Inc. The new pickup provides more sensitive and reliable acceleration measurements than did the earlier version, which, despite slight erratic changes during its operation, has been successfully applied to both field and laboratory acceleration measurements. Among such uses have been acceleration measurements on pilot ejection devices for high-speed aircraft, in landing impact tests for model aircraft, as well as on aircraft in actual flight.

The vacuum-tube acceleration pickup is a twindiode vacuum-tube consisting of a fixed, indirectly heated cathode and two plates, one on each side of the cathode. The plates are elastically mounted so that they will be deflected if the base of the tube is accelerated in a direction perpendicular to the plane of the plates. The new model differs from earlier versions in having stops to limit the motion of the plates, support rods 0.010 inch in diameter to increase the sensitivity of the tube, and a second getter.

The primary design requirement met by the Ramberg vacuum-tube accelerometer is its provision for an electrical signal of sufficient strength to drive directly a high-frequency recording galvanometer and at the same





The Ramberg vacuum-tube accelerometer makes possible more sensitive and reliable acceleration measurements in a wide variety of applications. Left: The accelerometer is being used to measure the vibration amplitude of a structural model of an airplane wing that is vibrating at its natural frequency. One pickup (in circle) is used to maintain the vibration at a constant level; the other is moved along the model to measure the variation of vibration amplitude with position. A close-up of the accelerometer is shown at right.

time have a relatively high natural vibration frequency. In the operation of the original model erratic changes, or "zero shifts," in its balance point were sometimes encountered. The source of this difficulty has been eliminated in the new model. The zero shift, resulting from excessive accelerations to the pickup while handling and installing, is prevented by stops that were added to limit the plate excursion and thus prevent overloading. Zero drift, believed to be due to small fluctuations in the cathode electron emission, has been effectively reduced by 3 steps: First, the accelerometer was given an aging treatment that made its emission nearly constant; second, 2 "getters" instead of 1 were used to improve the electrical characteristics; and third, the sensitivity was increased by a factor of 25 to make the remaining random output negligible compared with the output due to acceleration.

Because of promising results obtained with both the original and improved tube, an extended developmental project on the fundamentals of acceleration measurements is now under way as part of the NBS program on basic instrumentation, which is cooperatively supported by the Office of Naval Research, the Office of Air Research, and the Atomic Energy Commission. The objectives of this project are to obtain accelerometers having a greater range of acceleration measurement, higher output voltages, and damping of the natural frequency response. The accelerometers will be equipped with compact protective cases and mounting lugs for installation.

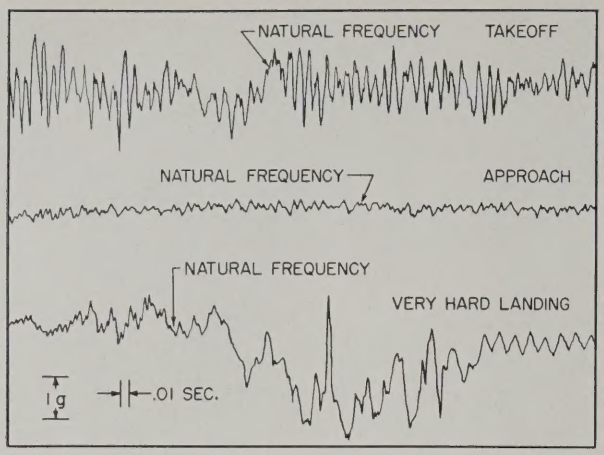
Accelerometer Characteristics

To evaluate the performance charactertistics of the accelerometer, its natural frequency was determined experimentally by connecting it to a specially designed Wheatstone bridge circuit that allows the output from each plate to be obtained separately. This output was applied to the vertical plates of an oscilloscope whose horizontal plates were connected to an audio oscillator. The accelerometer was then tapped gently to excite its natural vibration and the audio oscillator adjusted until the oscilloscope showed a Lissajous ellipse. The frequency of the oscillator for this condition was taken as the natural frequency of the particular accelerometer plate being tested. The natural frequencies of the plates of seven different accelerometers were within 1 cycle per second of the average value of 161 cycles.

The plate-to-cathode resistances were measured after a warming-up time of 20 minutes. The heater voltage was set at 7 volts and the plate voltage at 10 volts—the normal operating voltages for which the accelerometer was designed. Resistances were found to range between 118.3 and 263.5 ohms. The ratio of the two plate resistances for a given accelerometer fell between 1.01 and 1.91. A calibration factor was computed from measurements of the average percentage change in plate resistance per gravity (g) when the accelerometer was reversed in the earth's gravitational field. The values of the calibration factor for the seven pickups ranged between 8.6 and 11.6 percent per g.

The accelerometer output in the range from 1 g to -1 g was also determined by connecting it in a bridge circuit and mounting the accelerometer so that it could be set at prescribed angles in the earth's gravitational field. The current output per g of the bridge circuit into a 9-ohm galvanometer for the seven accelerometers tested was between 3.5 and 7.3 milliamperes. The voltage output of the bridge circuit into an oscilloscope was 0.72 to 1.00 volt per g.

The "zero drift" test was conducted after a 20-minute warm-up by measuring plate resistances and unbalance at 10-minute intervals over a period of 4 hours. During this test, the vacuum tube was mounted rigidly with the plates in a vertical plane. Zero drift in g units was obtained by dividing the zero drift in milliamperes by



Tracings of an oscillogram of the vertical accelerations to which the rear cockpit of a TBD airplane was subjected during take-off, approach, and landing. Note that the natural frequency response of the instrument itself (160 cps) is small compared to the response proportional to the imposed accelerations.

the output of the tube in milliamperes for 1 *g* change in acceleration. The largest zero drift over the 4-hour period for the seven tubes tested was 0.040 *g*; the smallest was 0.006 *g*. This magnitude of zero drift is appreciably less than that for the earlier type of tubes.

The maximum *g* for each tube—the *g* that caused the plates to contact the stops or the cathode—was determined by mounting the tubes on a centrifuge previously developed at the Bureau and applying acceleration until the output reached a maximum. Measurements were taken for accelerations in both directions normal to the plates, placing the maximum for the seven accelerometers tested between 9.3 and 13.3 *g*.

Field Tests

Field tests of the improved accelerometer have provided interesting and striking results that suggest the wide variety of uses to which such a sensitive device may be applied. For example, with the accelerometer clamped to the dashboards in 1936 and 1947 automobiles (and using a filter to eliminate natural frequency response), comparative records were obtained of the vertical accelerations to which the vehicles were subjected when crossing multiple streetcar tracks. Vertical accelerations experienced by the rear cockpit of a TBD airplane during takeoff, approach, and landing were likewise recorded by rigidly clamping the accelerometer to the structure. The natural frequency response of the instrument itself at 160 cycles per second in these records is small compared to the response proportional to the imposed accelerations.

Variations in the vertical accelerations of a freight elevator going from the first to the second floor were also readily revealed by the accelerometer. The increase in acceleration when the elevator was put in operation, the nearly zero change in acceleration between floors, and the decrease in acceleration while stopping were clearly shown in the continuous acceleration record. The natural frequency response is again small compared to the acceleration response. In this test, the circuit was modified by replacing a 1,400-ohm resistor in the filter circuit by one of 100 ohms. This resulted in a much higher sensitivity with some lowering of the attenuation at the cutoff frequency of the filter circuit.

The circuit used in the field tests of the improved pickup is an adaptation of the Kelvin double-bridge designed to minimize the effect of contact resistance both in the tube socket and in the adjustable rheostats. Because of the convenience of obtaining 6 volts from a storage battery, 6 volts were used for the heater voltage in these tests rather than the 7 volts for which the heater is designed. A blocking filter was used ahead of the galvanometer to eliminate the possible 160-cycles output at the natural frequency of the accelerometer. The characteristics of the over-all circuit were found to be flat within 5 percent up to 20 cycles per second and to attenuate gradually to nearly 100 percent at 160 cycles.

The accelerometer in its present form provides a useful addition to available measuring equipment for conducting field tests similar to those described above where accelerations up to about 5 *g* at frequencies up to about 20 cycles are to be measured. However, experience with the accelerometer indicates that it would be improved by the addition of a suitable protective cover with a convenient means for attachment, and by the provision of a mechanical means for damping vibration of the plates at their natural frequency. Work is now in progress to develop modified designs of the accelerometer to cover other acceleration ranges, as well as models having high plate resistance to give the high voltage output required for many electronic applications.

Note. Details of the original version of the tube are covered in Vacuum tube acceleration pickup, by Walter Ramberg, J. Research NBS ***37****, 391 (1946); also The measurement of acceleration with a vacuum tube, by Walter Ramberg, Amer. Inst. of Elec. Eng., Transactions,* ***66****, 735 (1947).*

See Calibration of accelerometers, by Samuel Levy, Albert E. McPherson, and Edward V. Hobbs, J. Research NBS ***41****, 359 (1948).*

Annual Report of the NBS for 1949

A summary of scientific investigations carried on at the National Bureau of Standards during the fiscal year 1949 is contained in a 101-page illustrated booklet just issued by the Bureau. Scientific activities at the Bureau were conducted by 13 divisions concerned with electronics, applied mathematics, atomic and radiation physics, radio propagation, electricity and optics, metrology, heat and power, chemistry, mechanics, organic and fibrous materials, metallurgy, mineral products, and building technology. Projects of greatest general interest and widest application have been selected for description.

Miscellaneous Publication 198, *Annual Report of the National Bureau of Standards for 1949*, is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., for 75 cents a copy.

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, volume **45**, number 5, November 1950 (RP2145 to RP2154, incl.)

Technical News Bulletin, volume **34**, number 11, November 1950, 10 cents.

CRPL-D75. Basic Radio Propagation Predictions for February 1951. Three months in advance. Issued November 1950. 10 cents.

Research Papers

RP2133. An iteration method for the solution of the eigen-value problem of linear differential and integral operators. Cornelius Lanczos. 15 cents.

RP2134. Measurement of the internal diameters of metallic capillary tubes. Charles T. Collett, John C. Hughes, and Francis C. Morey. 10 cents.

RP2135. Mass spectra of some simple isotopic molecules. Vernon H. Dibeler, Fred L. Mohler, Edmund J. Wells, Jr., and Robert M. Reese. 10 cents.

RP2136. Response characteristics of temperature-sensing elements for use in the control of jet engines. Andrew I. Dahl and Ernest F. Fiock. 10 cents.

RP2137. Dielectric constants of aqueous solutions of dextrose and sucrose. Cyrus G. Malmberg and Arthur A. Maryott. 10 cents.

RP2138. Response of accelerometers to transient accelerations. Samuel Ievy and Wilhelminia D. Kroll. 10 cents.

RP2139. Electrode deterioration in transmit-receive tubes. Judson C. French. 10 cents.

RP2140. Test mixtures for distillation at atmospheric and reduced pressure. Charles B. Willingham and Vincent A. Sedlak. 10 cents.

RP2141. Aging of karakul and seal fur skins. Edward T. Steiner and Elizabeth R. Hosterman. 10 cents.

RP2142. Second dissociation constant of succinic acid from 0° to 50° C. Gladys D. Pinching and Roger G. Bates. 10 cents.

RP2143. Methods of sieve analysis with particular reference to bone char. Frank G. Carpenter and Victor R. Deitz. 15 cents.

RP2144. First spectrum of arsenic. William F. Meggers, Allen G. Shenstone, and Charlotte E. Moore. 10 cents.

Publications in Other Journals

Modification of electron microscope for electron optical shadow method. J. Arol Simpson and Alan Van Bronkhorst. Rev. Sci. Instr. (57 East Fifty-fifth Street, New York 22, N. Y.) **21**, 669 (1950).

Degradation of high polymers. (Letter to the editor). Robert Simha. J. Polymer Sci. (215 Fourth Avenue, New York 3, N. Y.) **5**, 515 (1950).

Influence of temperature on the adsorption of water vapor by collagen and leather. J. R. Kanagy. J. Am. Leather Chem. Assn. (Campus Station, Cincinnati 21, Ohio) **45**, 12 (1950).

For wear prevention. S. A. McKee, J. F. Swindells, H. S. White, and W. Mountjoy. SAE Journal (33 West Thirty-ninth Street, New York 18, N. Y.) **58**, 47 (1950).

Interdisciplinary approach to science personnel. Mary E. Stevens. Personnel Administration (PO Box 266, Benj. Franklin Station, Washington 4, D. C.) **12**, No. 3, 27 (1950).

American Dental Association Specifications No. 9 for dental silicate cement. First revision, effective July 1, 1950. G. C. Paffenbarger, A. C. Swaney, I. C. Schoonover, and G. Dickson. J. Am. Dental Assoc. (222 East Superior Street, Chicago, Ill.) **40**, 186 (1950).

Units of radioactivity. L. F. Curtiss, R. D. Evans, Warren Johnson, and Glenn T. Seaborg. Rev. Sci. Instr. (57 East Fifty-fifth Street, New York 22, N. Y.) **21**, 94 (1950).

Remote-control method of opening ampoules of active material. Jesse E. Sherwood. Rev. Sci. Instr. (57 East Fifty-fifth Street, New York 22, N. Y.) **21**, 570 (1950).

Identification and microdetermination of nickel. H. I. Feinstein. Anal. Chem. (1155 Sixteenth Street, N. W., Washington 6, D. C.) **22**, 723 (1950).

VTM circuits. Myron C. Selby. Electronics (330 West 42nd Street, New York 18, N. Y.) **23**, No. 5, 110 (1950).

The influence of the ground on the calibration and use of VHF field-intensity meters. F. M. Greene. Proc. IRE (1 East 79th Street, New York 21, N. Y.) **38**, 650 (1950).

Electron optical properties of space-charged clouds. L. Marton and D. L. Reverdin. J. App. Phys. (57 East Fifty-fifth Street, New York 22, N. Y.) **21**, 842 (1950).

Present status of standards for shoe last sizes. R. B. Hobbs. J. Nat. Assoc. Chiropodists (3500 Fourteenth Street, N. W., Washington 10, D. C.) **40**, No. 10, 30 (1950).

Effects of acid treatment on acid and abrasion resistance of porcelain enamels. W. N. Harrison, J. C. Richmond, and J. R. Crandall. J. Am. Ceramic Soc. (2525 N. High Street, Columbus 2, Ohio) **33**, 314 (1950).

A thickness gage for ceramic coatings. C. C. Gordon and J. C. Richmond. J. Am. Ceramic Soc. **33**, 295 (1950).

Propagation of sound in rarefied helium. Martin Greenspan. J. Acoustical Soc. Am. (57 East Fifty-fifth Street, New York 22, N. Y.) **22**, 568 (1950).

Rate of shrinkage of tendon collagen: Further effects of tannage and liquid environment on the activation constants of shrinkage. C. E. Weir and J. Carter. J. Am. Leather Chem. Assn. (Campus Station, Cincinnati 21, Ohio) **45**, 421 (1950).

A summation method of O. Perron. Otto Szasz. Mathematische Zeitschrift (Berlin, Germany) **52**, 1 (1949).

The incorporation of subroutines into a complete problem on the NBS eastern automatic computer. Math Tables and Other Aids to Computation (2101 Constitution Avenue, N. W., Washington 25, D. C.) **4**, No. 31, 164 (1950).

Atomic definition of primary standards. R. D. Huntoon and U. Fano. Nature (MacMillan & Co., Ltd., St. Martin's Street, London W. C. 2 England) **166**, 167 (1950).

An instrument for mechanically differentiating curves. A. H. Scott. Rev. Sci. Instr. (57 East Fifty-fifth Street, New York 22, N. Y.) **21**, 397 (1950).

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